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DECLARATION

I, Yoichi ISHIGURO, of Yokohama Works of SUMITOMO ELECTRIC INDUSTRIES, LTD. 1, Taya-cho, Sakae-ku, Yokohama-shi, Kanagawa, Japan do solemnly and sincerely declare, that I well understand the Japanese language and English language and that the attached document is a full and faithful translation of a certified copy of the Japanese Patent Application No. 2000-248627 entitled "RAMAN AMPLIFIER AND OPTICAL COMMUNICATION SYSTEM" consisting of a certification duly certified by the Director General of the Patent Office and the specification.

This 20th day of June, 2003

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[Title of the Invention] RAMAN AMPLIFIER AND OPTICAL COMMUNICATION
SYSTEM

[Claims]

5 [Claim 1] A Raman amplifier comprising:

a plurality of optical fibers for Raman amplification whose optical waveguide regions have different compositions and through which signal lights are subjected to Raman amplification by supplying pump light for Raman amplification; and

10 a pump light supplying means for supplying the pump light to each of the plurality of optical fibers.

[Claim 2] A Raman amplifier according to Claim 1, wherein the plurality of optical fibers are connected in series.

[Claim 3] A Raman amplifier according to Claim 1, wherein the plurality of optical fibers are connected in parallel.

15 [Claim 4] A Raman amplifier according to Claim 1, wherein the pump light supplying means supplies pump light for Raman amplification of the same wavelength to each of the plurality of optical fibers.

[Claim 5] A Raman amplifier according to Claim 1, wherein the pump light supplying means supplies the pump light output from the pump light source, which is
20 a common pump light source, to each of the plurality of optical fibers.

[Claim 6] A Raman amplifier according to Claim 1, wherein the pump light supplying means supplies pump light for Raman amplification of different wavelengths to each of the plurality of optical fibers.

[Claim 7] A Raman amplifier according to Claim 1, wherein the optical waveguide
25 region of any one of the optical fibers is doped with germanium.

[Claim 8] A Raman amplifier according to Claim 1, wherein the optical waveguide region of any one of the optical fibers is doped with phosphorus.

[Claim 9] An optical communication system comprising:

optical transmission lines comprising a plurality of optical fibers for Raman
30 amplification whose optical waveguide regions have different compositions and through which signal lights are subjected to Raman amplification by supplying pump light for Raman amplification; and

a pump light supplying means for supplying the pump light to the optical transmission lines.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention]

The present invention relates to a Raman amplifier that compensates by
5 Raman amplification transmission loss that a signal light suffers when it is
transmitted in an optical transmission line in an optical communication system for
performing communication using the signal light.

[0002]

[Description of the Related Art]

10 In an optical communication system for performing communication using a
signal light, a signal light transmitted from a transmitter suffers transmission loss
when it is transmitted in an optical transmission line, and consequently its power
decreases when it reaches a receiver. If the power of the signal light which has
reached the receiver is equal to or less than a given value, normal optical
15 communication may not be achieved due to a reception error. Therefore, an optical
amplifier is disposed between the transmitter and the receiver and the signal light is
optically amplified by the optical amplifier in order to compensate such transmission
loss that the signal light suffers when it is transmitted in the optical transmission
line.

20 [0003]

Examples of such an optical amplifier are a rare earth element doped optical
fiber amplifier using a rare-earth-doped optical fiber for amplification (such as an Er
doped optical fiber amplifier) and a Raman amplifier making use of Raman
amplification phenomenon in an optical fiber for Raman amplification. Compared to
25 a rare earth element doped optical fiber amplifier, a Raman amplifier has, for
example, the characteristic that its spectrum band having gain can be set at a desired
value by properly setting the wavelength of pump light for Raman amplification.

[0004]

In a Wavelength Division Multiplexing (WDM) optical communication system
30 for performing optical communication by multiplexing signal lights having a plurality
of wavelengths in a predetermined signal light spectrum band, a Raman amplifier is
required to amplify the signal lights in a wide spectrum band or a plurality of
spectrum bands. For example, in Literature, Y. Emori, et al., "100 nm bandwidth flat
gain Raman amplifiers pumped and gain-equalized by 12-wavelength-channel WDM

high power laser diodes", OFC '99, PD19 (1999), there is disclosed a Raman amplifier in which an attempt is made to, for example, increase the width of a gain spectrum by supplying multiplexed light beams of different wavelengths output from a certain number N of pump light sources ($N \geq 2$) as pump light for Raman amplification to an optical fiber for Raman amplification. In the Literature, the number N of pump light sources is 12.

[0005]

[Problems to be Solved by the Invention]

However, in the Raman amplifier disclosed in the aforementioned Literature, since many pump light sources are required for, for example, increasing the width of a gain spectrum, costs are increased. If a Raman amplifier is provided for every repeater section, the number of optical pump sources required is equal to the product of the number of repeater sections and the aforementioned N value, so that costs are increased as expected.

[0006]

The present invention has been achieved to overcome the aforementioned problems, and has as its object the provision of a Raman amplifier and an optical communication system which make it possible to, for example, increase the width of a Raman amplification gain spectrum at low cost.

[0007]

[Means for Solving the Problems]

A Raman amplifier of the present invention comprises (1) a plurality of optical fibers for Raman amplification whose optical waveguide regions have different compositions and through which signal lights are subjected to Raman amplification by supplying pump light for Raman amplification, and (2) a pump light supplying means for supplying the pump light to each of the plurality of optical fibers. According to this Raman amplifier, when the pump light supplying means supplies pump light for Raman amplification to the optical fibers for Raman amplification, the signal lights transmitted through the optical fibers for Raman amplification are subjected to Raman amplification. Since the compositions of the optical waveguide regions of the respective optical fibers for Raman amplification differ from each other, their Stokes shifts also differ. Therefore, Raman amplification gain bandwidths in the optical fibers for Raman amplification can differ from each other. The Raman amplification gain bandwidth in the Raman amplifier is equal to the sum of the

Raman amplification gain bandwidths in the individual optical fibers for Raman amplification, so compared to the gain bandwidth of a related Raman amplifier having only one type of optical fiber for Raman amplification, the gain bandwidth of the Raman amplifier of the present invention can be widened.

5 [0008]

In the Raman amplifier of the present invention, the plurality of optical fibers for Raman amplification may be connected in series or in parallel. In either case, compared to the gain bandwidth in a related Raman amplifier, the Raman amplification gain bandwidth in the Raman amplifier of the present invention can be
10 widened. When the optical fibers for Raman amplification are connected in parallel, the signal lights are demultiplexed into spectrum bands by a demultiplexer and subjected to Raman amplification according to bandwidth by any one of the optical fibers for Raman amplification. In contrast, when the optical fibers for Raman amplification are connected in series, a multiplexer and a demultiplexer, which are
15 required when the optical fibers are connected in parallel, are not required, and therefore costs are reduced.

[0009]

In the Raman amplifier of the present invention, the pump light supplying means may supply pump light for Raman amplification of the same wavelength to
20 each of the plurality of optical fibers. In this case, the gain bandwidth in the Raman amplifier is in correspondence with the composition of each optical fiber for Raman amplification.

[0010]

In the Raman amplifier of the present invention, the pump light supplying
25 means may supply the pump light output from the pump light source, which is a common pump light source, to each of the plurality of optical fibers. This is more desirable because costs can be reduced due to the use of fewer pump light sources.

[0011]

In the Raman amplifier of the present invention, the pump light supplying
30 means may supply pump light for Raman amplification of different wavelengths to each of the plurality of optical fibers. The gain bandwidth in the Raman amplifier is in correspondence with both the composition of each optical fiber for Raman amplification and the wavelength of the pump light for Raman amplification, and therefore the bandwidth can be made even wider.

[0012]

In the Raman amplifier of the present invention, the optical waveguide region in any of the optical fibers for Raman amplification may be doped with germanium. Alternatively, the optical waveguide region in any of the optical fibers for Raman amplification may be doped with phosphorus. In either case, the gain bandwidth in the any of the optical fibers for Raman application is in correspondence with the added germanium or phosphorus, which is desirable with regard to setting the gain bandwidth of the Raman amplifier.

[0013]

An optical communication system of the present invention comprises (1) optical transmission lines comprising a plurality of optical fibers for Raman amplification whose optical waveguide regions have different compositions and through which signal lights are subjected to Raman amplification by supplying pump light for Raman amplification, and (2) a pump light supplying means for supplying the pump light to the optical transmission lines. According to the optical communication system, when the pump light supplying means supplies pump light for Raman amplification to the optical transmission lines comprising a plurality of optical fibers for Raman amplification, the signal lights that are transmitted through the optical transmission lines are subjected to Raman amplification. The compositions of the optical waveguide regions of the respective optical fibers for Raman amplification differ from each other, so their Stokes shifts also differ. Therefore, the Raman amplification gain bandwidths in the optical fibers for Raman amplification can differ from each other. The Raman amplification gain bandwidth in the optical communication system is equal to the sum of the Raman amplification gain bandwidths in the individual optical fibers for Raman amplification, so, compared to the gain bandwidth of a related optical communication system having only one type of optical fiber for Raman amplification, the gain bandwidth in the optical communication system of the present invention can be widened.

[0014]

[Description of the Embodiments]

In the following, preferred embodiments of the present invention will be explained in detail with reference to the accompanying drawings. The same reference numerals denote the same parts throughout the drawings, and a repeated explanation will be omitted.

[0015]

(First Embodiment of Raman Amplifier)

First, a description of a Raman amplifier of a first embodiment of the present invention will be given. Figure 1 illustrates the structure of a Raman amplifier 10 of the first embodiment. The Raman amplifier 10 is provided with a first optical fiber 11₁ for Raman amplification, a first multiplexer/demultiplexer 12₁, an optical isolator 13, a second optical fiber 11₂ for Raman amplification, and a second multiplexer/demultiplexer 12₂ from an input end 10a to an output end 10b in the enumerated order. In addition, the Raman amplifier 10 is provided with a pump light source 14 that is connected to both the first multiplexer/demultiplexer 12₁ and the second multiplexer/demultiplexer 12₂.

[0016]

The pump light source 14 outputs pump light for Raman amplification. The first multiplexer/demultiplexer 12₁ supplies the pump light output from the pump light source 14 to the first optical fiber 11₁ for Raman amplification, and allows signal lights, which have reached it from the first optical fiber 11₁ for Raman amplification, to pass to the optical isolator 13. The second multiplexer/demultiplexer 12₂ supplies the pump light output from the pump light source 14 to the second optical fiber 11₂ for Raman amplification, and allows signal lights, which have reached it from the second optical fiber 11₂ for Raman amplification, to pass towards the output end 10b.

[0017]

The first optical fiber 11₁ for Raman amplification transmits signal lights, which have been input from the input end 10a, toward the first multiplexer/demultiplexer 12₁ and Raman-amplifies the signal lights as a result of the pump light being supplied from the first multiplexer/demultiplexer 12₁. The optical isolator 13 allows light to pass in the direction from the first multiplexer/demultiplexer 12₁ to the second optical fiber 11₂ for Raman amplification, but does not allow the light to pass in the opposite direction. The second optical fiber 11₂ for Raman amplification transmits signal lights, which have been input from the optical isolator 13, towards the second multiplexer/demultiplexer 12₂, and Raman-amplifies the signal lights as a result of the pump light being supplied from the second multiplexer/demultiplexer 12₂.

[0018]

In the Raman amplifier 10, the pump light that has been output from the

pump light source 14 is branched into two to be supplied to the first optical fiber 11₁ for Raman amplification via the first multiplexer/demultiplexer 12₁ and to the second optical fiber 11₂ for Raman amplification via the second multiplexer/demultiplexer 12₂. Then, the signal lights, which have been input to the input end 10a, propagate
 5 through the first optical fiber 11₁ for Raman amplification while they are being Raman-amplified, pass through the first multiplexer/demultiplexer 12₁ and the optical isolator 13, then propagate through the second optical fiber 11₂ for Raman amplification while they are being Raman-amplified, and are output from the output end 10b via the second multiplexer/demultiplexer 12₂.

10 [0019]

In particular, in the Raman amplifier 10, the two optical fibers 11₁ and 11₂ for Raman amplification differ from each other with respect to the compositions of their respective optical waveguide regions and they are connected in series. Pump light for Raman amplification having an identical wavelength that has been output from the
 15 common pump light source 14 is supplied to each of the two optical fibers 11₁ and 11₂ for Raman amplification. Since the optical fibers 11₁ and 11₂ for Raman amplification differ from each other with respect to the compositions of their respective optical waveguide regions including core areas, their Stokes shifts also differ, and therefore their Raman amplification gain bandwidths differ from each other.

20 [0020]

Figure 2 is a graph showing the relationship between Stokes shift and Raman scattering intensity with respect to the composition of each optical fiber. As shown in Fig. 2, the Stokes shift in which Raman scattering intensity becomes the greatest in each optical fiber differs depending upon the composition. For example, in the case of
 25 GeO₂, the Raman scattering intensity becomes the greatest when the Stokes shift is about 420 cm⁻¹; and, in the case of P₂O₅, the Raman scattering intensity becomes the greatest when the Stokes shift is about 635 cm⁻¹. In the case of B₂O₃, the Raman scattering intensity becomes the greatest when the Stokes shift is about 825 cm⁻¹. In the case of GeO₂ and P₂O₅, the Stokes shifts in which their Raman scattering
 30 intensities become maximum are, when expressed in terms of a wavelength unit, about 100 nm.

[0021]

Figure 3 is a graph showing the relationship between the wavelength of pump light for Raman amplification and the Raman amplification gain spectrum. As shown

in Fig. 3(a), when the Stokes shift of the first optical fiber 11₁ for Raman amplification is a, the first optical fiber 11₁ has a gain spectrum centering around a wavelength that is longer than a wavelength λ of the pump light by the Stokes shift a. As shown in Fig. 3(b), when the Stokes shift of the second optical fiber 11₂ for Raman amplification is b, the second optical fiber 11₂ has a gain spectrum centering around a wavelength that is longer than a wavelength λ of the pump light by the Stokes shift b. In this case, as shown in Fig. 3(c), when the pump light having the same wavelength λ output from the common pump light source 14 is supplied to the optical fibers 11₁ and 11₂ for Raman amplification, the Raman amplification gain bandwidths in the optical fibers 11₁ and 11₂ differ from each other.

[0022]

For example, the first optical fiber 11₁ for Raman amplification may be a silica-based optical fiber whose optical waveguide region is doped with GeO₂, and the second optical fiber 11₂ for Raman amplification may be a silica-based optical fiber whose optical waveguide region is doped with P₂O₅. In this way, even if the pump light for Raman amplification having the same wavelength output from the common pump light source 14 is supplied, the Raman amplification gain bandwidths in the respective optical fibers 11₁ and 11₂ for Raman amplification differ from each other. The Raman amplification gain bandwidth in the Raman amplifier 10 is equal to the sum of the Raman amplification gain bandwidths in the individual optical fibers 11₁ and 11₂ for Raman amplification, so compared to the gain bandwidth of a related Raman amplifier having only one type of optical fiber for Raman amplification, the gain bandwidth of the Raman amplifier 10 of the first embodiment can be widened. As described above, the Raman amplifier 10 of the embodiment makes it possible to, for example, increase the width of a Raman amplification gain spectrum by using only one pump light source, so costs are reduced.

[0023]

(Second Embodiment of Raman Amplifier)

Next, a description of a Raman amplifier of a second embodiment of the present invention will be given. Figure 4 illustrates the structure of a Raman amplifier 20 of the second embodiment. The Raman amplifier 20 is provided with a first optical fiber 21₁ for Raman amplification, a second optical fiber 21₂ for Raman amplification, and a multiplexer/demultiplexer 22 in the enumerated order from an input end 20a to an output end 20b. The Raman amplifier 20 is also provided with a

pump light source 24 that is connected with the multiplexer/demultiplexer 22.

[0024]

5 The pump light source 24 outputs pump light for Raman amplification. The multiplexer/demultiplexer 22 supplies the pump light output from the pump light source 24 to both the first optical fiber 21₁ for Raman amplification and the second optical fiber 21₂ for Raman amplification, and allows signal lights, which have reached it from the second optical fiber 21₂ for Raman amplification, to pass towards the output end 20b.

[0025]

10 The first optical fiber 21₁ for Raman amplification transmits signal lights, which have been input from the input end 20a, toward the second optical fiber 21₂ for Raman amplification, and also Raman-amplifies the signal lights as a result of the pump light being supplied from the multiplexer/demultiplexer 22. The second optical fiber 21₂ for Raman amplification transmits signal lights, which have been input from
15 the first optical fiber 21₁ for Raman amplification, toward the multiplexer/demultiplexer 22, and also Raman-amplifies the signal lights as a result of the pump light being supplied from the multiplexer/demultiplexer 22.

[0026]

20 In the Raman amplifier 20, the pump light for Raman amplification that has been output from the pump light source 24 is supplied to both the first optical fiber 21₁ for Raman amplification and the second optical fiber 21₂ for Raman amplification via the multiplexer/demultiplexer 22. Then, the signal lights that have been input to the input end 20a propagate through the first optical fiber 21₁ for Raman amplification and the second optical fiber 21₂ for Raman amplification while being
25 Raman-amplified, and are output from the output end 20b through the multiplexer/demultiplexer 22.

[0027]

30 In particular, in the Raman amplifier 20, the two optical fibers 21₁ and 21₂ for Raman amplification differ from each other with respect to the compositions of their respective optical waveguide regions and they are connected in series. Pump light for Raman amplification having an identical wavelength that has been output from the common pump light source 24 is supplied to each of the two optical fibers 21₁ and 21₂ for Raman amplification. Since the optical fibers 21₁ and 21₂ for Raman amplification differ from each other with respect to the compositions of their respective optical

waveguide regions including core areas, their Stokes shifts also differ, and therefore their Raman amplification gain bandwidths differ from each other.

[0028]

For example, the first optical fiber 21₁ for Raman amplification may be a silica-based optical fiber whose optical waveguide region is doped with GeO₂, and the second optical fiber 21₂ for Raman amplification may be a silica-based optical fiber whose optical waveguide region is doped with P₂O₅. In this way, even if the pump light for Raman amplification having the same wavelength output from the common pump light source 14 is supplied, the Raman amplification gain bandwidths in the respective optical fibers 21₁ and 21₂ for Raman amplification differ from each other. The Raman amplification gain bandwidth in the Raman amplifier 20 is equal to the sum of the Raman amplification gain bandwidths in the individual optical fibers 21₁ and 21₂ for Raman amplification, so compared to the gain bandwidth of a related Raman amplifier having only one type of optical fiber for Raman amplification, the gain bandwidth of the Raman amplifier 20 of the second embodiment can be widened. As described above, the Raman amplifier 20 of the embodiment makes it possible to, for example, increase the width of a Raman amplification gain spectrum by using only one pump light source, and therefore costs are reduced.

[0029]

20 (Third Embodiment of Raman Amplifier)

Next, a description of a Raman amplifier of a third embodiment of the present invention will be given. Figure 5 illustrates the structure of a Raman amplifier 30 of the third embodiment. The Raman amplifier 30 is provided with a first optical fiber 31₁ for Raman amplification, a first multiplexer/demultiplexer 32₁, an optical isolator 33, a second optical fiber 31₂ for Raman amplification, and a second multiplexer/demultiplexer 32₂ from an input end 30a to an output end 30b in the enumerated order. The Raman amplifier 30 is also provided with a first pump light source 34₁ that is connected to the first multiplexer/demultiplexer 32₁ and with a second pump light source 34₂ that is connected to the second multiplexer/demultiplexer 32₂.

[0030]

The first pump light source 34₁ and the second pump light source 34₂, respectively, output pump light for Raman amplification. The first multiplexer/demultiplexer 32₁ supplies the pump light, which has been output from

the first pump light source 34₁, to the first optical fiber 31₁ for Raman amplification, and also allows signal lights, which have reached it from the first optical fiber 31₁ for Raman amplification, to pass towards the optical isolator 33. The second multiplexer/demultiplexer 32₂ supplies the pump light, which has been output from the second pump light source 34₂, to the second optical fiber 31₂ for Raman amplification, and also allows signal lights, which have reached it from the second optical fiber 31₂ for Raman amplification, to pass toward the output end 30b.

[0031]

The first optical fiber 31₁ for Raman amplification transmits signal lights, which have been input from the input end 30a, toward the third multiplexer/demultiplexer 32₁ and Raman-amplifies the signal lights as a result of the pump light being supplied from the first multiplexer/demultiplexer 32₁. The optical isolator 33 allows light to pass in the direction from the first multiplexer/demultiplexer 32₁ to the second optical fiber 31₂ for Raman amplification, but does not allow the light to pass in the opposite direction. The second optical fiber 31₂ for Raman amplification transmits signal lights, which have been input from the optical isolator 33, towards the second multiplexer/demultiplexer 32₂, and Raman-amplifies the signal lights as a result of the pump light being supplied from the second multiplexer/demultiplexer 32₂.

[0032]

In the Raman amplifier 30, the pump light that has been output from the first pump light source 34₁ is supplied to the first optical fiber 31₁ for Raman amplification via the first multiplexer/demultiplexer 32₁, and the pump light that has been output from the second pump light source 34₂ is supplied to the second optical fiber 31₂ for Raman amplification via the second multiplexer/demultiplexer 32₂. Then, signal lights that have been input to the input end 30a propagate through the first optical fiber 31₁ for Raman amplification while they are being Raman-amplified, pass through the first multiplexer/demultiplexer 32₁ and the optical isolator 33, propagate through the second optical fiber 31₂ for Raman amplification while they are being Raman-amplified, and are output from the output end 30b via the second multiplexer/demultiplexer 32₂.

[0033]

In particular, in the Raman amplifier 30, the two optical fibers 31₁ and 31₂ for Raman amplification differ from each other with respect to the compositions of their

respective optical waveguide regions and they are connected in series. Since the optical fibers 31₁ and 31₂ for Raman amplification differ from each other with respect to the compositions of their respective optical waveguide regions including core areas, their Stokes shifts also differ. For example, the first optical fiber 31₁ for Raman amplification may be a silica-based optical fiber whose optical waveguide region is doped with GeO₂, and the second optical fiber 31₂ for Raman amplification may be a silica-based optical fiber whose optical waveguide region is doped with P₂O₅.

[0034]

A wavelength λ_1 of the pump light output from the first pump light source 34₁ and supplied to the first optical fiber 31₁ for Raman amplification, and a wavelength λ_2 of the pump light output from the second pump light source 34₂ and supplied to the second optical fiber 31₂ for Raman amplification may be identical or may differ from each other.

[0035]

When the wavelength λ_1 and the wavelength λ_2 are the same, the optical fibers 31₁ and 31₂ for Raman amplification have different Raman amplification gain bandwidths as in the case of the first or second embodiment. On the other hand, when the wavelength λ_1 and the wavelength λ_2 are different from each other, the Raman amplification gain bandwidths in the optical fibers 31₁ and 31₂ for Raman amplification may be further separated from each other, or may partly overlap each other. (Refer to Fig. 3(d).) In either case, the Raman amplification gain bandwidth in the Raman amplifier 30 is equal to the sum of the Raman amplification gain bandwidths in the individual optical fibers 31₁ and 31₂ for Raman amplification, so compared to the gain bandwidth of a related Raman amplifier having only one type of optical fiber for Raman amplification, the gain bandwidth of the Raman amplifier 30 of the third embodiment can be widened. As described above, the Raman amplifier 30 of the embodiment makes it possible to, for example, increase the width of a Raman amplification gain spectrum by using only two pump light sources, and therefore costs are reduced.

[0036]

(Fourth Embodiment of Raman Amplifier)

Next, a description of a Raman amplifier of a fourth embodiment of the present invention will be given. Figure 6 illustrates the structure of a Raman amplifier 40 of the fourth embodiment. The Raman amplifier 40 is provided with a first optical fiber

41₁ for Raman amplification and a second optical fiber 41₂ for Raman amplification, which are connected together in parallel, and with a demultiplexer 45 disposed between these optical fibers and an input end 40a. The Raman amplifier 40 is also provided with a multiplexer/demultiplexer 42₁ and a multiplexer/demultiplexer 42₂, and a multiplexer 46, which are disposed between the optical fibers and an output end 40b. The Raman amplifier 40 is further provided with a pump light source 44 that is connected to both the first multiplexer/demultiplexer 42₁ and second multiplexer/demultiplexer 42₂.

[0037]

The pump light source 44 outputs pump light for Raman amplification. The first multiplexer/demultiplexer 42₁ supplies the pump light output from the pump light source 44 to the first optical fiber 41₁ for Raman amplification, and also allows signal lights, which have reached it from the first optical fiber 41₁ for Raman amplification, to pass toward the optical multiplexer 46. The second multiplexer/demultiplexer 42₂ supplies the pump light output from the pump light source 44 to the second optical fiber 41₂ for Raman amplification, and also allows signal lights, which have reached it from the second optical fiber 41₂ for Raman amplification, to pass toward the optical multiplexer 46.

[0038]

The demultiplexer 45 demultiplexes signal lights, which have been input from an input end 10a, into a first spectrum band and a second spectrum band, and outputs the signal lights in the first spectrum band to the first optical fiber 41₁ for Raman amplification and outputs the signal lights in the second spectrum band to the second optical fiber 41₂ for Raman amplification. The first optical fiber 41₁ for Raman amplification transmits the signal lights in the first spectrum band that have reached it from the demultiplexer 45 toward the first multiplexer/demultiplexer 42₁, and Raman-amplifies the signal lights as a result of the pump light being supplied from the first multiplexer/demultiplexer 42₁. The second optical fiber 41₂ for Raman amplification transmits the signal lights in the second spectrum band that have reached it from the demultiplexer 45 toward the second multiplexer/demultiplexer 42₂, and Raman-amplifies the signal lights as a result of the pump light being supplied from the second multiplexer/demultiplexer 42₂. The optical multiplexer 46 multiplexes the signal lights in the first spectrum band that have reached it from the first multiplexer/demultiplexer 42₁ and the signal lights in the second spectrum band

that have reached it from the second multiplexer/demultiplexer 42₂, and outputs the multiplexed signal lights toward the output end 40b.

[0039]

In the Raman amplifier 40, the pump light for Raman amplification that has
5 been output from the pump light source 44 is branched into two to be supplied to the first optical fiber 41₁ for Raman amplification via the first multiplexer/demultiplexer 42₁ and to the second optical fiber 41₂ for Raman amplification via the second multiplexer/demultiplexer 42₂. Then, the signal lights that have been input to the input end 40a are demultiplexed into the first spectrum band and the second
10 spectrum band by the demultiplexer 45. The signal lights in the first spectrum band propagate through the first optical fiber 41₁ for Raman amplification while they are being Raman-amplified and travel toward the optical multiplexer 46 via the first multiplexer/demultiplexer 42₁. The signal lights in the second spectrum band propagate through the second optical fiber 41₂ for Raman amplification while they are
15 being Raman-amplified and travel toward the optical multiplexer 46 via the second multiplexer/demultiplexer 42₂. The signal lights in the first and second spectrum bands are multiplexed by the optical multiplexer 46 and are output from the output end 40b.

[0040]

In particular, in the Raman amplifier 40, the two optical fibers 41₁ and 41₂ for Raman amplification differ from each other with respect to the compositions of their respective optical waveguide regions and they are connected in parallel. Pump light for Raman amplification having an identical wavelength that has been output from the common pump light source 44 is supplied to each of the two optical fibers 41₁ and
20 41₂ for Raman amplification. Since the optical fibers 41₁ and 41₂ for Raman amplification differ from each other with respect to the compositions of their respective optical waveguide regions including core areas, their Stokes shifts also differ, and therefore their Raman amplification gain bandwidths differ from each other.

30 [0041]

For example, the first optical fiber 41₁ for Raman amplification may be a silica-based optical fiber whose optical waveguide region is doped with GeO₂, and the second optical fiber 41₂ for Raman amplification may be a silica-based optical fiber whose optical waveguide region is doped with P₂O₅. In this way, even if the pump light for

Raman amplification having the same wavelength output from the common pump light source 44 is supplied, the Raman amplification gain bandwidths in the respective optical fibers 41₁ and 41₂ for Raman amplification differ from each other. The Raman amplification gain bandwidth in the Raman amplifier 40 is equal to the
5 sum of the Raman amplification gain bandwidths in the individual optical fibers 41₁ and 41₂ for Raman amplification, so compared to the gain bandwidth of a related Raman amplifier having only one type of optical fiber for Raman amplification, the gain bandwidth of the Raman amplifier 40 of the fourth embodiment can be widened. As described above, the Raman amplifier 40 of the embodiment makes it possible to,
10 for example, increase the width of a Raman amplification gain spectrum by using only one pump light source, and therefore costs are reduced.

[0042]

Although, in this embodiment, pump light for Raman amplification having the same wavelength is supplied to the two optical fibers 41₁ and 41₂ for Raman
15 amplification, pump light for Raman amplification having different wavelengths may be supplied thereto.

[0043]

(Embodiment of Optical Communication System)

Next, an optical communication system of an embodiment of the present
20 invention will be described. Figure 7 illustrates the structure of an optical communication system 1 of the embodiment. The optical communication system 1 is composed of optical transmission lines connecting a transmitting station 61 and a repeater station 62, the repeater station 62 and a repeater station 63, and the repeater station 63 and a receiving station 64.

25 [0044]

The optical transmission line between the transmitting station 61 and the repeater station 62 is formed of an optical fiber 51₁ for Raman amplification. The optical transmission line between the repeater station 62 and the repeater station 63 is formed of optical fibers 51₂ and 51₃ for Raman amplification. The repeater station
30 62 is provided with a pump light source 54₁ that outputs pump light for Raman amplification and a multiplexer/demultiplexer 52₁ for introducing the pump light, which has been output from the pump light source 54₁, into the optical fiber 51₁ for Raman amplification. The repeater station 63 is provided with a pump light source 54₂ that outputs pump light for Raman amplification and a multiplexer/demultiplexer

52₂ for introducing the pump light, which has been output from the pump light source 54₂, into the optical fibers 51₂ and 51₃ for Raman amplification. That is, the optical fiber 51₁ for Raman amplification, the pump light source 54₁, and the multiplexer/demultiplexer 52₁ constitute the Raman amplifier. Also, the optical fibers 51₂ and 51₃ for Raman amplification, the pump light source 54₁, and the multiplexer/demultiplexer 52₁ constitute the Raman amplifier.

[0045]

In the optical communication system 1, the pump light for Raman amplification that has been output from the pump light source 54₁ in the repeater station 62 is supplied to the optical fiber 51₁ for Raman amplification via the multiplexer/demultiplexer 52₁. The pump light that has been output from the pump light source 54₂ in the repeater station 63 is supplied to the optical fibers 51₂ and 51₃ for Raman amplification via the multiplexer/demultiplexer 52₂. Then, signal lights that have been output from the transmitting station 61 propagate through the optical fiber 51₁ for Raman amplification toward the repeater station 61 while they are being Raman-amplified, and further propagate through the optical fibers 51₂ and 51₃ for Raman amplification toward the repeater station 62 while they are being Raman-amplified, and further propagate through the optical transmission line to the receiving station 64 and are received by the receiving station 64.

[0046]

In particular, in the optical communication system 1, the three optical fibers 51₁ to 51₃ differ from each other with respect to the compositions of their respective optical waveguide regions, and they are connected in series. Pump light of the same wavelength output from the common pump light source 54₂ is supplied to each of the two optical fibers 51₂ and 51₃ for Raman amplification. Since the optical fibers 51₁ to 51₃ for Raman amplification differ from each other with respect to the compositions of their respective optical waveguide regions including core areas, their Stokes shifts also differ, and therefore their Raman amplification gain bandwidths differ from each other.

[0047]

By way of example, any one of the optical fibers 51₁ through 51₃ for Raman amplification may be a silica-based optical fiber whose optical waveguide region is doped with GeO₂ and any one of the other optical fibers may be a silica-based optical fiber whose optical waveguide region is doped with P₂O₅. Accordingly, the Raman

amplification gain bandwidths in the optical fibers 51₁ to 51₃ for Raman amplification are different from each other. The Raman amplification gain bandwidth in the optical communication system 1 is equal to the sum of the Raman amplification gain bandwidths in the individual optical fibers 51₁ and 51₃ for Raman amplification, so compared to the gain bandwidth of a related optical communication system having only one type of optical fiber for Raman amplification, the gain bandwidth of the optical communication system 1 of the present invention can be widened. As described above, the optical communication system 1 of the embodiment makes it possible to, for example, increase the width of a Raman amplification gain spectrum by using only three pump light sources, and therefore costs are reduced.

[0048]

[Advantages]

As described in detail above, according to the Raman amplifier of the present invention, when the pump light supplying means supplies pump light for Raman amplification to the optical fibers for Raman amplification, the signal lights transmitted through the optical fibers for Raman amplification are subjected to Raman amplification. Since the compositions of the optical waveguide regions of the respective optical fibers for Raman amplification differ from each other, their Stokes shifts also differ. In this manner, the Raman amplification gain bandwidths in the optical fibers for Raman amplification can differ from each other. The Raman amplification gain bandwidth in the Raman amplifier is equal to the sum of the Raman amplification gain bandwidths in the individual optical fibers for Raman amplification, so compared to the gain bandwidth of a related Raman amplifier having only one type of optical fiber for Raman amplification, the gain bandwidth of the Raman amplifier of the present invention can be widened. Therefore, the Raman amplifier makes it possible to, for example, increase the width of a Raman amplification gain spectrum by using a small number of pump light sources, and therefore costs are reduced.

[0049]

It is desirable that the optical fibers for Raman amplification be connected in parallel from the viewpoint that the signal lights are demultiplexed into spectrum bands by a demultiplexer and subjected to Raman amplification according to bandwidth by any one of the optical fibers for Raman amplification. Alternatively it

from the viewpoint that costs are reduced because a multiplexer and a demultiplexer, which are required when the optical fibers are connected in parallel, are not required.

[0050]

When the pump light supplying means supplies pump light for Raman
 5 amplification of the same wavelength to each of the plurality of optical fibers, the gain
 bandwidth in the Raman amplifier is in correspondence with the composition of each
 optical fiber for Raman amplification. It is more desirable that the pump light
 supplying means supply the pump light output from the pump light source, which is a
 common pump light source, to each of the plurality of optical fibers because costs can
 10 be reduced due to the use of fewer pump light sources. When the pump light
 supplying means supplies pump light for Raman amplification of different
 wavelengths to each of the plurality of optical fibers, the gain bandwidth in the
 Raman amplifier is in correspondence with both the composition of each optical fiber
 for Raman amplification and the wavelength of the pump light for Raman
 15 amplification, so the bandwidth can be made even wider.

[0051]

It is desirable that the optical waveguide region in any of the optical fibers for
 Raman amplification be doped with germanium. Alternatively, it is desirable that the
 optical waveguide region in any of the optical fibers for Raman amplification be doped
 20 with phosphorus. In either case, the gain bandwidth in the any of the optical fibers
 for Raman application is in correspondence with the added germanium or phosphorus,
 which is desirable with regard to setting the gain bandwidth of the Raman amplifier.

[0052]

According to the optical communication system, when the pump light
 25 supplying means supplies pump light for Raman amplification to the optical
 transmission lines comprising a plurality of optical fibers for Raman amplification,
 signal lights that are transmitted through the optical transmission lines are subjected
 to Raman amplification. The compositions of the optical waveguide regions of the
 respective optical fibers for Raman amplification differ from each other, so their
 30 Stokes shifts also differ. In this manner, the Raman amplification gain bandwidths in
 the optical fibers for Raman amplification can differ from each other. The Raman
 amplification gain bandwidth in the optical communication system is equal to the
 sum of the Raman amplification gain bandwidths in the individual optical fibers for
 Raman amplification, as compared to the gain bandwidth of a related optical

communication system having only one type of optical fiber for Raman amplification, the gain bandwidth in the optical communication system of the present invention can be widened. Therefore, the optical communication system makes it possible to, for example, increase the width of a Raman amplification gain spectrum by using a small number of pump light sources, and therefore costs are reduced.

[Brief Description of the Drawings]

[Fig. 1]

Figure 1 illustrates the structure of a Raman amplifier 10 of a first embodiment.

10 [Fig. 2]

Figure 2 is a graph showing the relationship between Stokes shift and Raman scattering intensity with respect to the composition of each optical fiber.

[Fig. 3]

Figure 3 is a graph showing the relationship between the wavelength of pump light for Raman amplification and Raman amplification gain spectrum.

[Fig. 4]

Figure 4 illustrates the structure of a Raman amplifier 20 of a second embodiment.

[Fig. 5]

20 Figure 5 illustrates the structure of a Raman amplifier 30 of a third embodiment.

[Fig. 6]

Figure 6 illustrates the structure of a Raman amplifier 40 of a fourth embodiment.

25 [Fig. 7]

Figure 7 illustrates the structure of an optical communication system 1 of an embodiment.

[Reference Numerals]

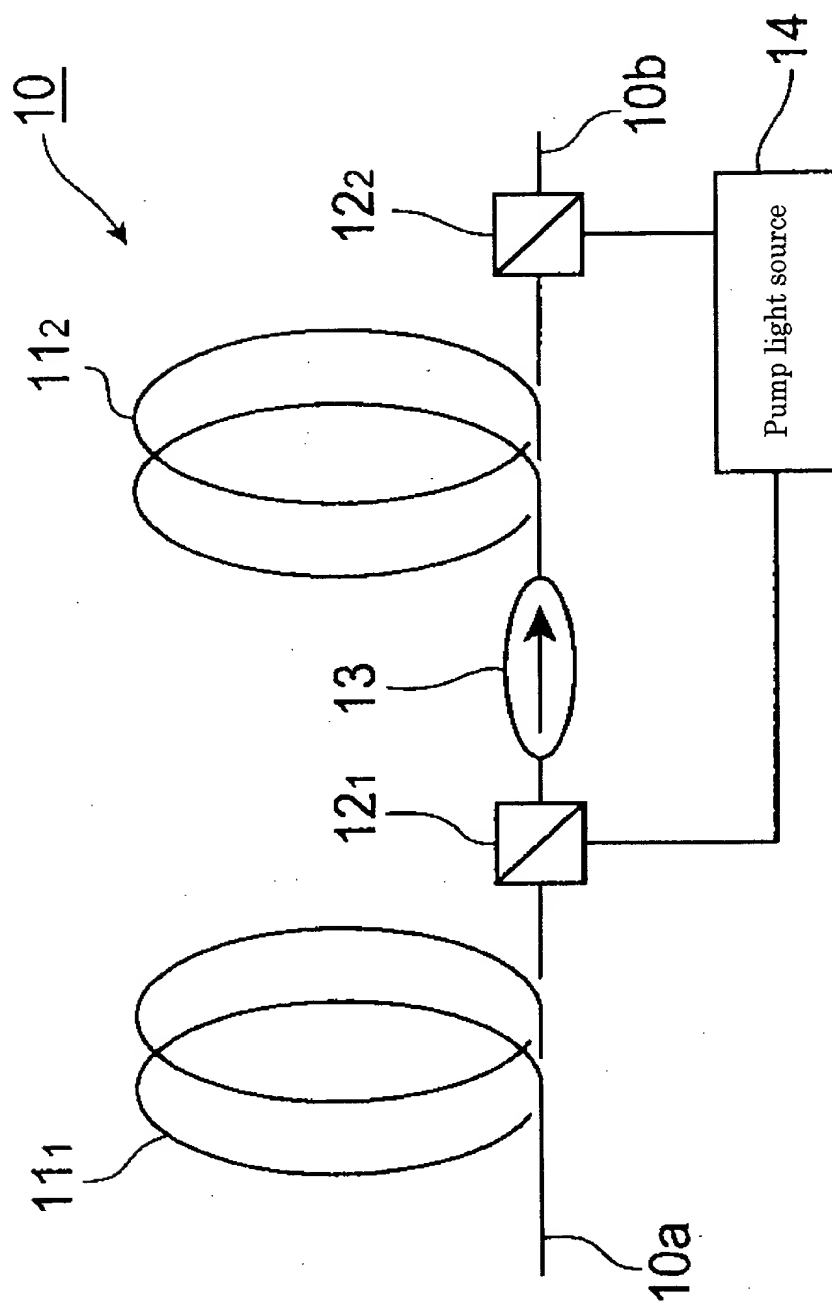
- 1: optical communication system
- 30 10: Raman amplifier
- 11₁, 11₂: optical fiber for Raman amplification
- 12₁, 12₂: multiplexer/demultiplexer
- 13: optical isolator

	20: Raman amplifier
	21 ₁ , 21 ₂ : optical fiber for Raman amplification
	22: multiplexer/demultiplexer
	24: pump light source
5	30: Raman amplifier
	31 ₁ , 31 ₂ : optical fiber for Raman amplification
	32 ₁ , 32 ₂ : multiplexer/demultiplexer
	33: optical isolator
	34 ₁ , 34 ₂ : pump light source
10	40: Raman amplifier
	41 ₁ , 41 ₂ : optical fiber for Raman amplification
	42 ₁ , 42 ₂ : multiplexer/demultiplexer
	44: pump light source
	45: demultiplexer
15	46: optical multiplexer
	51 ₁ to 51 ₃ : optical fiber for Raman amplification
	52 ₁ , 52 ₂ : multiplexer/demultiplexer
	54 ₁ , 54 ₂ : pump light source
	61: transmitting station
20	62, 63: repeater station
	64: receiving station

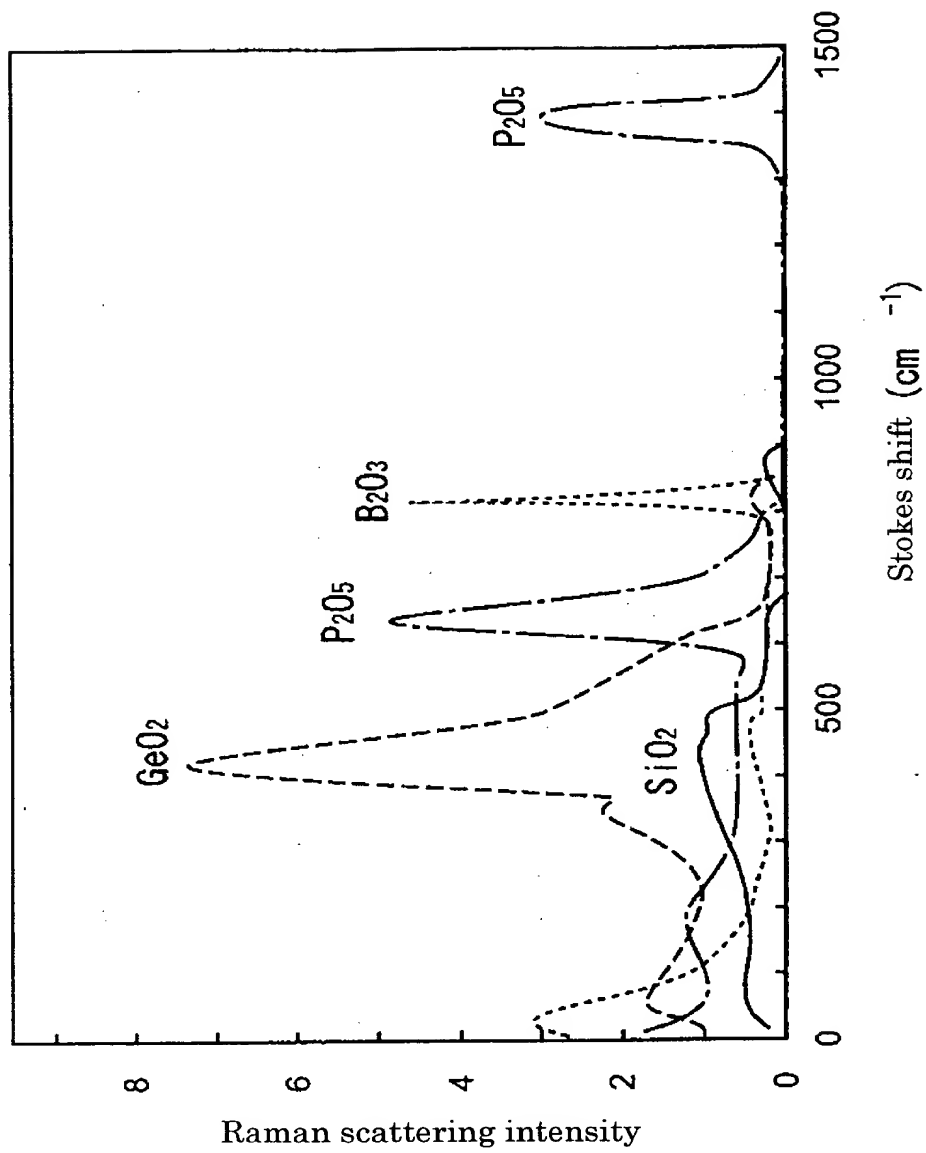
[Document name]

Drawings

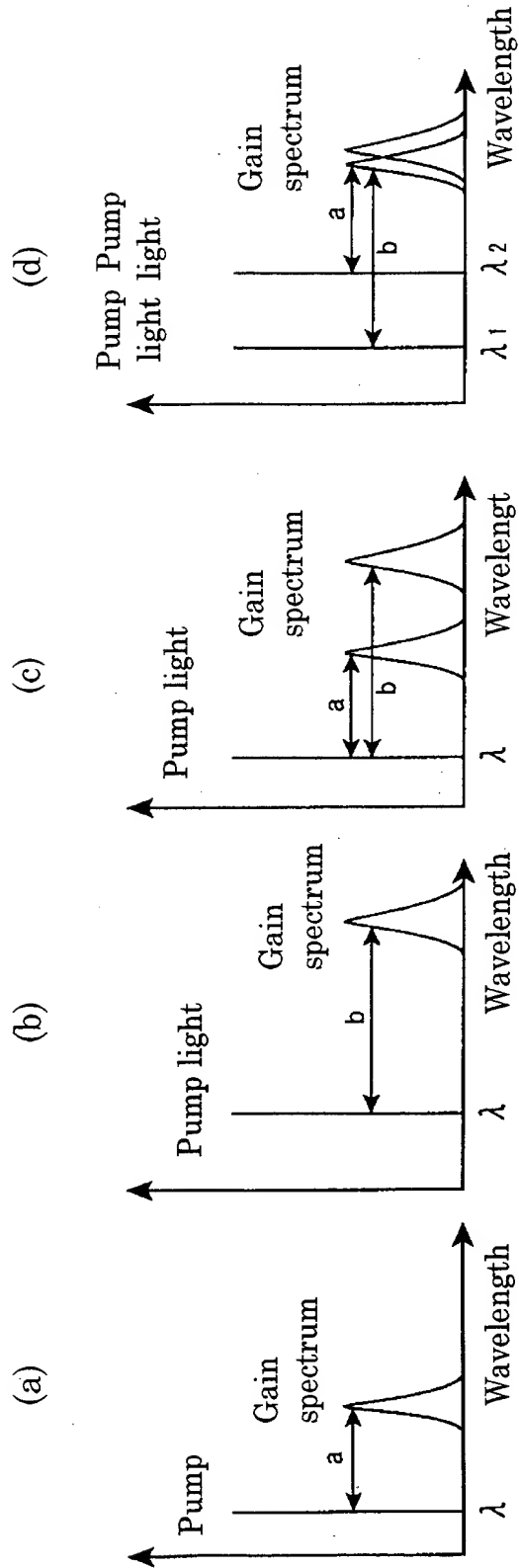
[Figure 1]

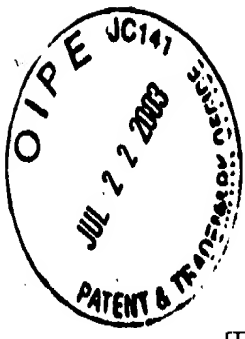


[Figure 2]

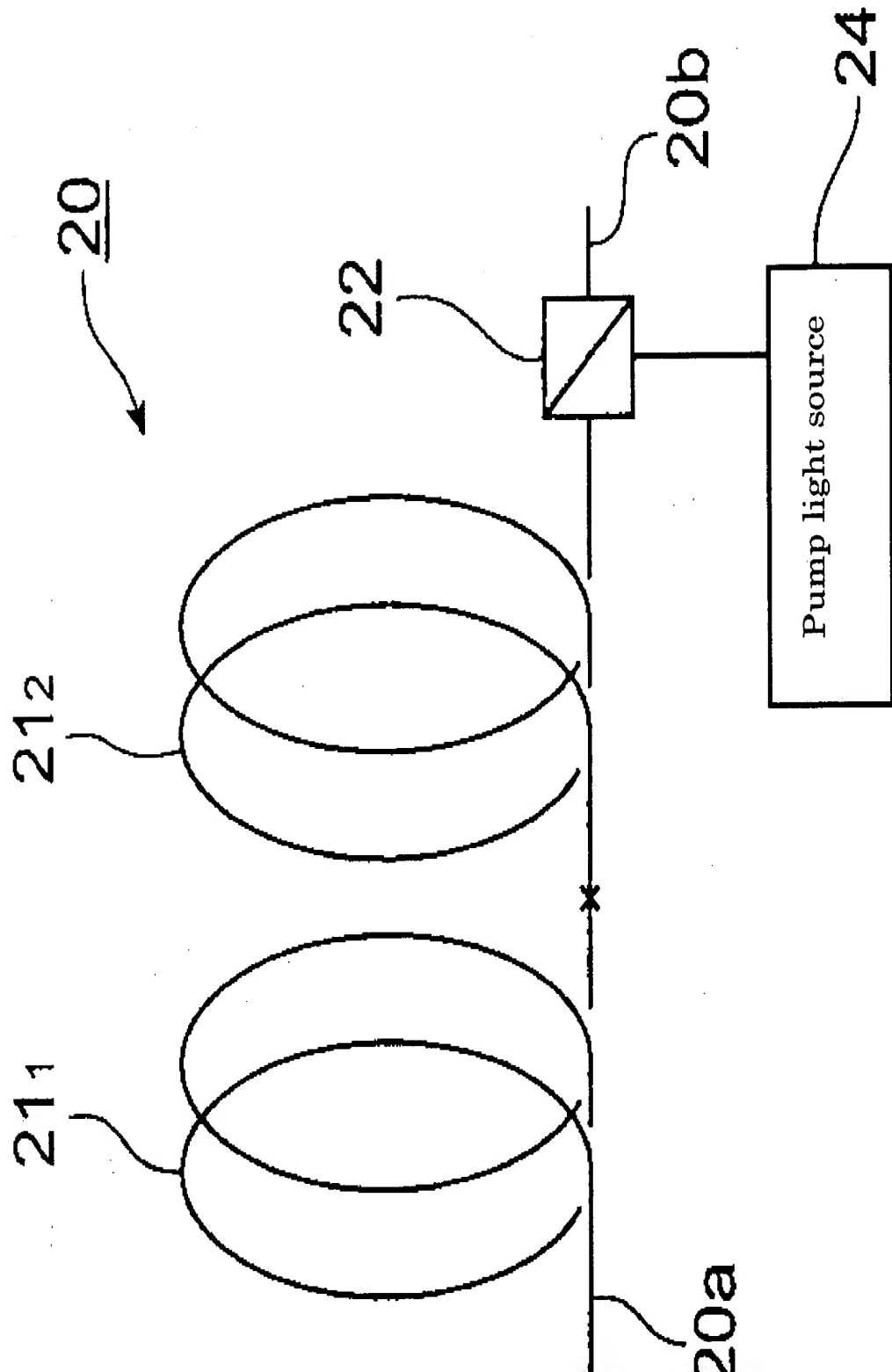


[Figure 3]

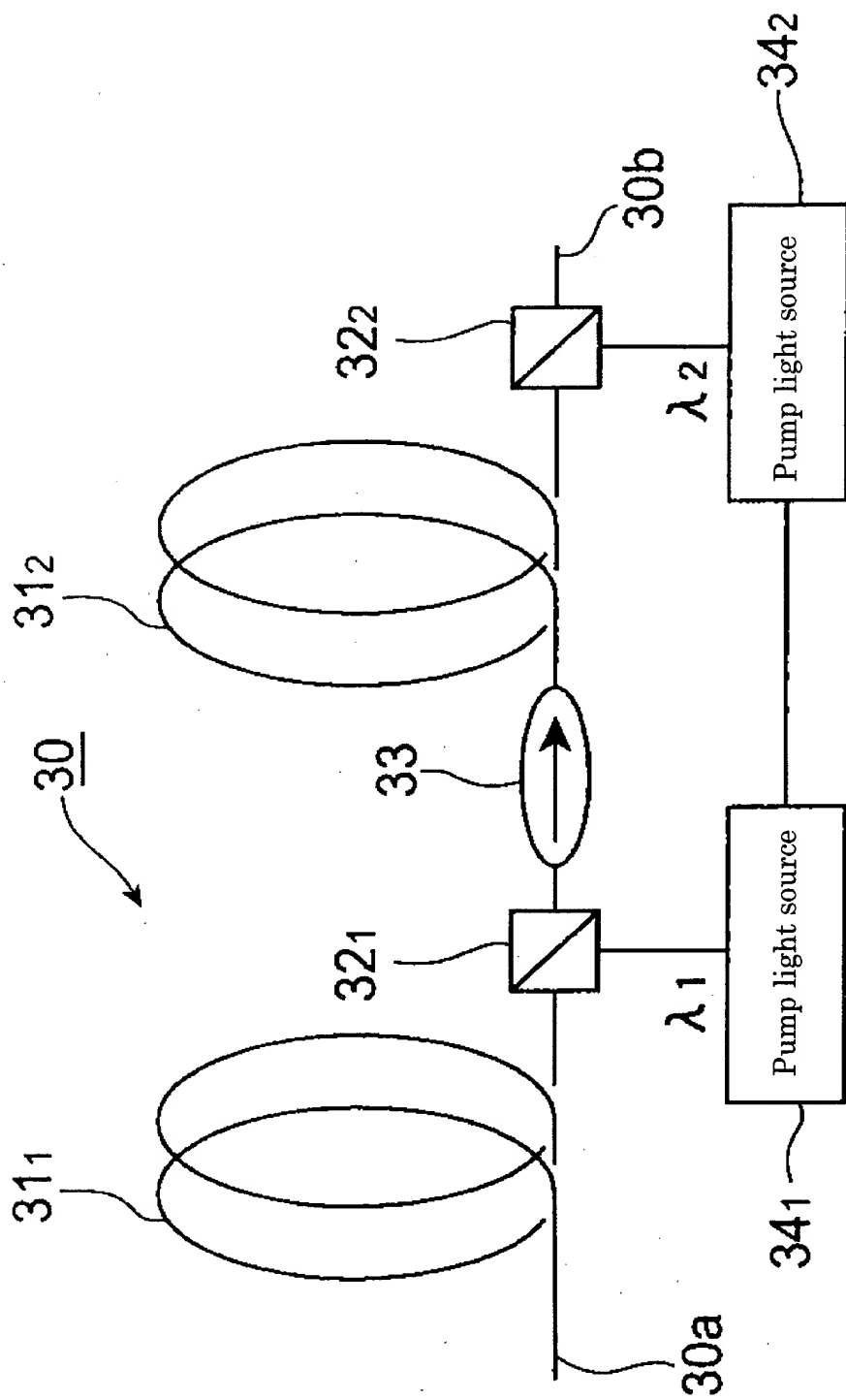




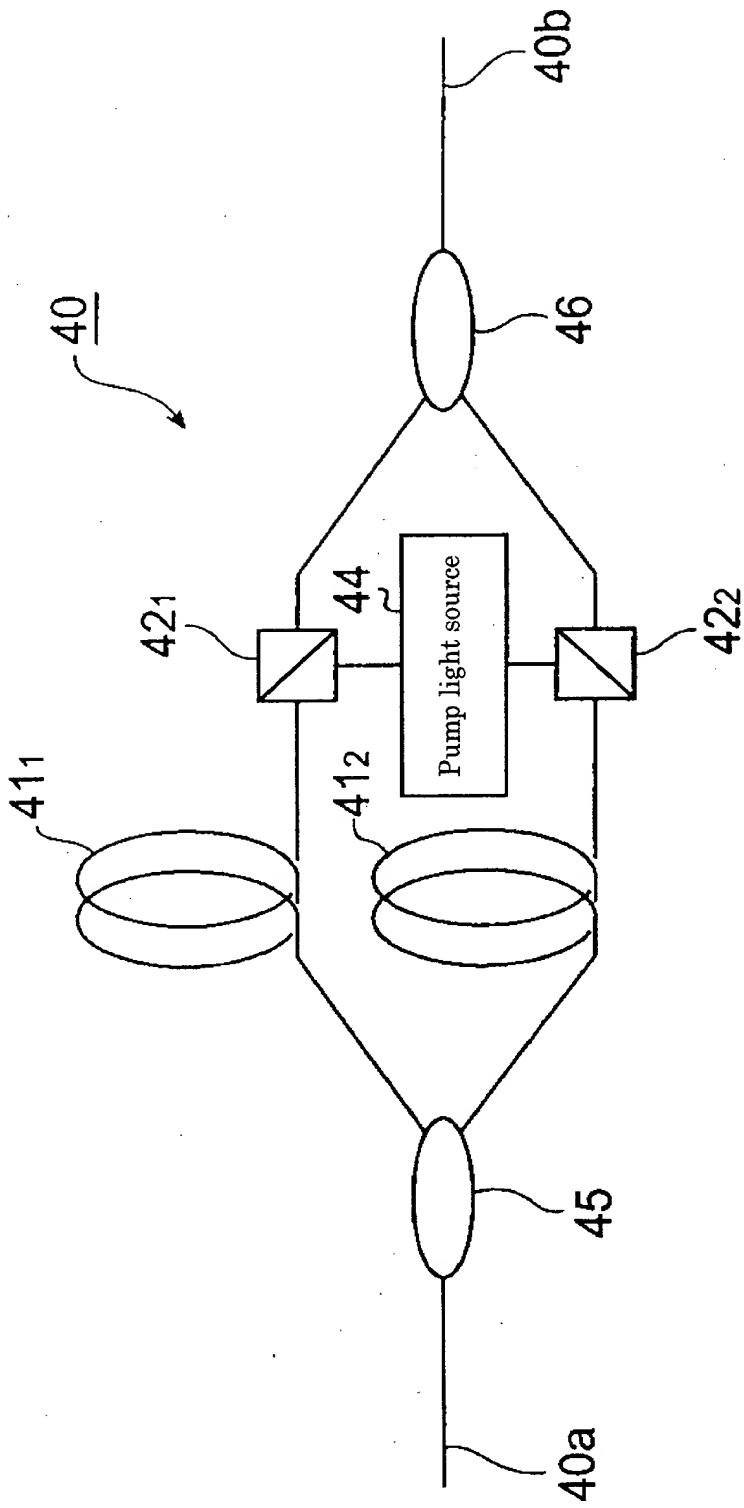
[Figure 4]



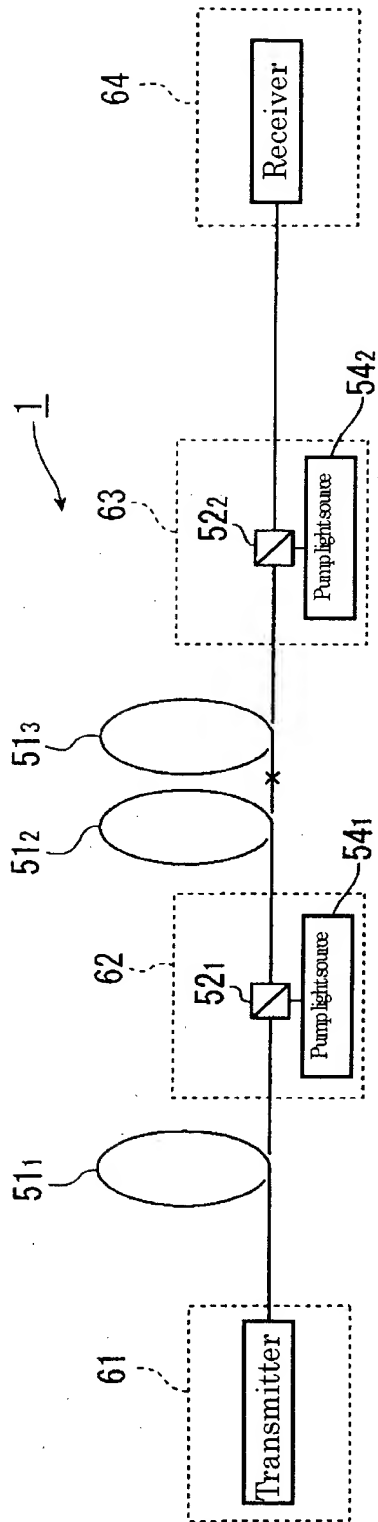
[Figure 5]

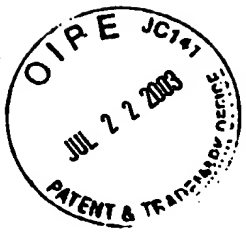


[Figure 6]



[Figure 7]





[Document name] ABSTRACT

[Abstract]

[Object] To provide a Raman amplifier and an optical communication system which make it possible to, for example, increase the width of a gain spectrum for Raman
5 amplification at a low cost.

[Solving Means] In a Raman amplifier 10, pump light that has been output from a pump light source 14 is branched into two to be supplied to a first optical fiber 11₁ for Raman amplification via a first multiplexer/demultiplexer 12₁ and to a second optical fiber 11₂ for Raman amplification via a second multiplexer/demultiplexer 12₂. Then,
10 signal lights, which have been input to an input end 10a, propagate through the first optical fiber 11₁ for Raman amplification while they are being Raman-amplified, pass through the first multiplexer/demultiplexer 12₁ and an optical isolator 13, then propagate through the second optical fiber 11₂ for Raman amplification while they are
15 being Raman-amplified, and are output from an output end 10b via the second multiplexer/demultiplexer 12₂. The two optical fibers 11₁ and 11₂ for Raman amplification differ from each other with respect to the compositions of their respective optical waveguide regions and they are connected in series.

[Selected Figure] Fig. 1

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